Advanced National Seismic System

Performance Standards

The Earthquake Hazards Reduction Act (P.L. 95–124 as amended) gives the USGS the Federal responsibility for providing notifications of earthquakes and its reauthorization in 2000 established the ANSS to modernize and expand the Nation's seismic monitoring infrastructure to provide accurate and timely data and information products for seismic events, including their effects on buildings and structures, employing modern monitoring methods and technologies.

This document establishes the standards for performance related to seismic monitoring, product generation, and data availability for the U.S. Geological Survey's (USGS) Earthquake Hazards Program (EHP) and governing the operation of the Advanced National Seismic System (ANSS). These standards are intended to assure quality and consistent performance within ANSS for all participants related to monitoring and evaluation of significant earthquakes nationwide. The standards and related metrics are, in some cases, aspirational, i.e., ANSS infrastructure and data processing capabilities may need to be improved for some ANSS participants.

All ANSS participants are required to follow these standards and procedures as well as all ANSS policies and the derivative standards, procedures, and specifications as they pertain to each participant's scope of operations and authority.

Performance Areas
Performance standards for the following ANSS performance are:

- **Seismic Monitoring/Strong Earthquake Shaking.** Collect accurate information on the occurrence of earthquakes and archive the appropriate data for seismic hazards and earthquake research. Accurately record large-amplitude earthquake ground motions that may cause damage to engineered structures or affect land use by causing liquefaction or other type of ground deformation.
- **Real-Time/Automated Product Generation.** When an earthquake occurs, rapidly and authoritatively compute earthquake source parameters and ground shaking maps (where appropriate), and distribute this information to emergency responders, the media, and the public.
- **Preparation of Seismologist-Reviewed Products for Significant Earthquakes**. Conduct seismologist review of earthquakes that may have seismic hazards or other societal implications. Provide useful, accurate, and timely release of products to communities most at risk from earthquakes likely to cause damage.
- **Data Exchange between ANSS Networks**. Exchange real-time waveforms, amplitudes, picks, and other raw data products between network centers, to improve quality and timeliness of data products.
- **Data Archiving and Public Distribution**. Archive all relevant data and data products generated by ANSS, including regional and global seismic networks at designated datacenter(s).

Geographic Divisions Based on Hazard, Risk and USGS Mission
Based on ANSS requirements and USGS mission responsibilities, standards for the following geographic areas are:

- **High-risk urban areas.** Twenty-six metropolitan areas listed in Table 3 (p. 42) of USGS Circular 1188, "Requirement for an Advanced National Seismic System" http://earthquake.usgs.gov/monitoring/anss/documents.php
- **Moderate-to-high hazard regions.** Areas of the 50 U.S. States and Puerto Rico having an earthquake hazard probability of 10% in 50 years for an acceleration ≥8%*g* (yellow and higher hazard areas on the map, below). This acceleration level is justified as the approximate threshold of damage to older dwellings or structures not made to resist earthquakes.
- **National.** Areas of the 50 States not included in the moderate-to-high hazard regions.
- **Global.** All areas outside the 50 States and Puerto Rico.

Maps of earthquake hazard in the U.S., including Alaska, Hawaii and Puerto Rico, are available at:

http://earthquake.usgs.gov/hazards/.

Performance Standards: The table below identifies minimum performance targets for the ANSS for each of the performance areas and geographic areas described above.

<table>
<tr><th colspan="3"></th><th colspan="4">Performance Standard</th></tr>
<tr><th colspan="2">Performance Area / Metric (explanations on following pages)</th><th>Units</th><th>Hi-Risk Urban Areas</th><th>Mod-High Hazard Areas</th><th>National</th><th>Global</th></tr>
<tr><td colspan="2">Seismic Monitoring/Strong Earthquake Shaking</td><td colspan="5"></td></tr>
<tr><td>1.1</td><td>Magnitude Completeness Level</td><td>M</td><td>2.0</td><td>2.5</td><td>3.0</td><td>4.5</td></tr>
<tr><td>1.2</td><td>Epicenter Uncertainty</td><td>km</td><td>2</td><td>5</td><td>10</td><td>20</td></tr>
<tr><td>1.3</td><td>Depth Uncertainty</td><td>km</td><td>4</td><td>10</td><td>10</td><td>20</td></tr>
<tr><td>1.4</td><td>Magnitude Uncertainty for $M \geq 4.5$</td><td>M</td><td colspan="4">±0.2</td></tr>
<tr><td>1.5</td><td>Magnitude Estimation Accuracy (Md, Ml, Mo, Mb) for $M < 4.5$</td><td>M</td><td colspan="3">to be determined</td><td>NA</td></tr>
<tr><td>1.6</td><td>Network average station uptime</td><td>%</td><td colspan="4">90</td></tr>
<tr><td>1.7</td><td>Waveform Data Return Rate for Triggered data</td><td>%</td><td colspan="3">95</td><td>NA</td></tr>
<tr><td colspan="2">Real-Time/Automated Product Generation</td><td colspan="5"></td></tr>
<tr><td>2.1</td><td>Hypocenter Post Time</td><td>min.</td><td>2</td><td>4</td><td>6</td><td>15</td></tr>
<tr><td>2.2</td><td>Magnitude Post Time</td><td>min.</td><td>3</td><td>4</td><td>6</td><td>15</td></tr>
<tr><td>2.3</td><td>Moment Tensor Post Time $M \geq 4.5$ ($M \geq 5.5$ non-US)</td><td>min.</td><td colspan="3">15</td><td>30</td></tr>
<tr><td>2.4</td><td>Initial COSMOS V0-V3 Products Post Time</td><td>min.</td><td>10</td><td>10</td><td>10</td><td></td></tr>
<tr><td>2.5</td><td>ShakeMap Post Time</td><td>min.</td><td>5</td><td>10</td><td>15</td><td>20</td></tr>
<tr><td colspan="2">Preparation of Seismologist-Reviewed Products for Significant Earthquakes</td><td colspan="5"></td></tr>
<tr><td>3.1</td><td>Reviewed Hypocenter Post Time</td><td>min.</td><td colspan="3">10</td><td>20</td></tr>
<tr><td>3.2</td><td>Reviewed Magnitude Post Time</td><td>min.</td><td colspan="3">10</td><td>20</td></tr>
<tr><td>3.3</td><td>Reviewed Moment Tensor Post Time $M \geq 4.5$ ($M \geq 5.5$ non-US)</td><td>min.</td><td colspan="4">30</td></tr>
<tr><td>3.4</td><td>Reviewed COSMOS V0-V3 Products Post Time</td><td>days</td><td>7</td><td>7</td><td>7</td><td></td></tr>
<tr><td>3.5</td><td>Reviewed ShakeMap Post Time</td><td>min.</td><td>15</td><td>30</td><td>30</td><td>60</td></tr>
<tr><td colspan="2">Data Exchange Between ANSS Participating Networks</td><td colspan="5"></td></tr>
<tr><td>4.1</td><td>Waveform Availability Timeliness</td><td>sec.</td><td colspan="2">30</td><td colspan="2">60</td></tr>
<tr><td>4.1.1</td><td>Waveform Availability Timeliness for ShakeAlert</td><td>sec.</td><td colspan="2">1</td><td colspan="2">NA</td></tr>
<tr><td>4.2</td><td>Amplitude Availability Timeliness</td><td>sec.</td><td colspan="2">30</td><td colspan="2">60</td></tr>
<tr><td>4.3</td><td>Phase Picks Availability Timeliness</td><td>sec.</td><td colspan="2">30</td><td colspan="2">60</td></tr>
<tr><td colspan="2">Data Archiving and Public Distribution</td><td colspan="5"></td></tr>
<tr><td>5.1</td><td>Availability of Waveforms to External Users</td><td>min.</td><td colspan="4">60</td></tr>
<tr><td>5.2</td><td>Availability of Event Bulletin (parametric data)</td><td>min.</td><td colspan="3">60</td><td>120</td></tr>
<tr><td>5.3</td><td>Metadata availability (current)</td><td>%</td><td colspan="4">99</td></tr>
<tr><td>5.4</td><td>Data import into archive</td><td>%/t</td><td colspan="4">to be determined</td></tr>
</table>

Explanations of Metrics

Seismic Monitoring/Strong Earthquake Shaking

1.1 Magnitude Completeness Level – Minimum magnitude above which 90% of earthquakes can be routinely located. Level will be estimated by a standard procedure such as the departure from the linear frequency-magnitude relation or probabilistic determination based on existing station distribution (to be determined).

1.2 Epicenter Uncertainty – Distance of calculated epicenter from true epicenter. For purposes of evaluating the performance of the ANSS, the uncertainty is estimated as the length of the largest projection of the three principal errors on a horizontal plane, where the one-standard deviation principal errors are the major axes of the error ellipsoid, and are mutually perpendicular. The metric does not account for location biases due to incorrectly modeled structure of the earth, which will be a subject for research with the ANSS observations.

1.3 Depth Uncertainty – Difference between calculated focal depth and true focal depth. For purposes of evaluating the performance of the ANSS, the uncertainty is estimated as the length of the largest projection of the three principal errors (as above) on a vertical line. The metric does not account for depth biases due to incorrectly modeled structure of the earth, which will be a subject for research with the ANSS observations.

1.4 Magnitude Uncertainty – Error in magnitude arising from inaccuracies in instrumental measurements of amplitude, amplitude and period, or velocity of ground motion. The magnitude uncertainty should be estimated from calibration of ANSS seismographs. The metric does not account for errors arising from inadequate knowledge of the velocity and attenuation structure of the earth, which will be a subject for research with ANSS observations and which, if incorrectly accounted for, may lead to calculated magnitudes being in error by several tenths of a magnitude unit.

1.5 Magnitude Estimation Accuracy (Md, Ml, Mo, Mb) for M<4.5 – Documented (preferably published) methodology that demonstrates accuracy of magnitude estimates.

1.6 Network average station uptime – In percent over the past year for every station utilizing continuous telemetry. Also to be reported as a network average of all stations (algorithm to be determined). The completeness of each continuous channel is estimated by comparing the number of available samples for the day to the number of expected samples as defined in metadata. This total is then reduced by the amount of time when a channel may have been dead, where a dead channel is defined as having a noise level more than an 5 dB below the NLNM in the 4–8 s period band. The network average uptime can then be computed as the average of all channels in the network.

1.7 Waveform Data Return Rate for Triggered data – in percent over the past year for every station utilizing event detection for 200 sps waveform recovery, based on either earthquakes of engineering interest or exceeding a trigger threshold [described in 2.4 below]. Also reported as a network average of all stations.

Real-Time/Automated Product Generation

2.1 Hypocenter Post Time – time interval between computed origin time and first submission of hypocenter into PDL.[1]

2.2 Magnitude Post Time – time interval between computed origin time and first submission of first magnitude into PDL.

2.3 Moment Tensor Post Time, M≥4.5 (M≥5.5 non-US) – time interval between computed origin time and first submission of first moment tensor into PDL.

[1] PDL is the acronym for the *Product Distribution Layer*, a USGS platform for exchanging information about seismic events. More information is available at http://ehppdl1.cr.usgs.gov/

2.4 Initial COSMOS V0-V3 products – First report of peak acceleration, velocity and displacement, and spectra parameters for earthquakes that meet the CESMD thresholds. Currently this is M3.0+ in the lower 48, M4.0+ in Hawaii, Alaska, and Puerto Rico. COSMOS V0-V3 Products are sent to the Center for Engineering Strong Motion Data (CESMD) for posting. In some cases, records that don't pass initial automated QC processing will be held for additional human review prior to posting at CESMD. In large earthquake sequences, these magnitude thresholds may be increased.

2.5 ShakeMap Post Time – time interval between computed origin time and first submission of ShakeMap products to PDL.

Preparation of Seismologist-Reviewed Products for Significant Earthquakes

3.1 Reviewed Hypocenter Post Time – time interval between computed origin time and submission of first human reviewed hypocenter into PDL.

3.2 Reviewed Magnitude Post Time – time interval between computed origin time and submission of first human reviewed magnitude into PDL.

3.3 Reviewed Moment Tensor Post Time, M≥4.5 (M≥5.5 non-US) – time interval between computed origin time and submission of first human reviewed moment tensor into PDL

3.4 Initially Reviewed COSMOS V0-V3 products – peak acceleration, velocity and displacement, time histories and spectra.

3.5 Reviewed ShakeMap Post Time – time interval between computed origin time and first submission of reviewed ShakeMap products to PDL.

Data Exchange between ANSS Participating Networks

4.1 Waveform Availability Timeliness – delay between time-stamp when data sample is acquired by an operating network and when it is exported from the network (owner and operator may be different.)

4.1.1 Waveform Availability Timeliness for ShakeAlert – delay between time-stamp when data sample is acquired by an operating network and when it is exported from the network for use by the ShakeAlert system (owner and operator may be different).

4.2 Amplitude Availability Timeliness – delay between time-stamp when data sample is determined by an operating network and when it is exported from the network.

4.3 Phase Picks Availability Timeliness – delay between time-stamp when data sample is determined by an operating network and when it is exported from the network.

Data Archiving and Public Distribution

5.1 Availability of Waveforms to External Users – delay between time-stamp when data sample is acquired by network and when it is available to external (public) users (e.g., from a searchable web page like SeismiQuery or via a request mechanism like *BREQ_FAST*).

5.2 Availability of Event Bulletin (parametric data) – delay between when data products are computed by network and when it is available to external (public) users either from a public datacenter or via a request mechanism (e.g., from a searchable web page or via a request mechanism).

5.3 Metadata availability (current data) – delay between when station comes on line and waveforms are available for export to seismic networks or to external (public) users and when metadata (*Dataless SEED*) are available either from a public datacenter or via a request mechanism (e.g., from a searchable web page using SeismiQuery or via a request mechanism like *BREQ_FAST*).

5.4 Data import into archive – delay between when data products and waveforms are created or acquired, respectively, and when they are sent to a facility for permanent archival.

Seismological Contexts of Performance Areas and Justifications of Specific Metrics

Seismic Monitoring – Metrics 1.2, 1.3, 1.4, 1.6, 1.7

Earthquakes occur throughout the US with varying frequency and are recorded by network operations centers throughout the country. In addition, US seismic networks record other seismic events, including explosions, quarry blasts, volcanic tremors, and teleseisms.

Goal: To monitor seismic activity throughout the US to catalog the occurrence of earthquakes and archive the appropriate data for seismic hazards and earthquake research.

Key Components: The standard for seismic activity involves both operations of seismic networks and generation of data products. Seismic networks continuously (24/7) operate remote seismic stations with dedicated telemetry and data acquisition systems. The data are initially processed using automated algorithms. Most networks also reprocess the data with human input to refine data quality before archiving.

The completeness level measures the minimum earthquake magnitude above which the network detects essentially all earthquakes. The standard applies to the average across the network's authoritative region. If significant equipment failures occur, it may not be possible to meet this standard for a few days or, possibly, weeks. The average location and magnitude uncertainties capture the overall network performance in terms of being able to produce a high quality catalog. The "magnitude capability" describes the uncertainties of magnitudes which the ANSS should be able to routinely calculate. The standard for "waveform data return rate for triggered data," tracks sensor reliability and communication reliability issues that could result in loss of seismic waveform data.

Comments:
The completeness level is difficult to determine and varies across the network's authoritative region; most networks have not carried out rigorous analysis of their catalog to determine the spatial and temporal variability of M. The ANSS National Implementation Committee must establish procedures for determining M and request that network operators do basic analysis of M spatial-temporal variability within their network.

The uncertainties in location and magnitude may be method dependent. The ANSS National Implementation Committee must adopt a standard for determining these parameters.

Justification
1. Completeness levels and location uncertainty are determined to provide sufficient data for identification and characterization of active faults, improved hazard estimates, recurrence intervals, etc. A threshold lower than the "felt limit" is necessary, particularly in less seismically active areas of the country and where station density permits, in order to build sufficiently large catalogs in a reasonable amount of time. The stated thresholds are reasonable estimates that can be met by the ANSS as outlined in USGS Circular 1188.
2. Magnitude capability includes types and errors that balance best practice for the CISN with a reasonable estimate of the capability of a completed ANSS.
3. The "Waveform Data Return Rate for Triggered data" balances the desire to have 100% availability with an experienced-based estimate of network performance.

Strong Earthquake Shaking – Metrics 1.5, 1.6, 1.7

Significant earthquakes of magnitude about 5 and greater have finite source dimensions that may extend from a few kilometers to 100s of kilometers. When such earthquakes occur, strong-motion acceleration recorders placed at free-field or reference sites record the felt to potentially violent and damaging shaking of the ground. Such data are used for many scientific, engineering, and emergency response purposes, including inferring the finite properties of the earthquake source, improving attenuation relationships and site effects models, compiling corrected time histories for use in code development and engineering design and analysis, and preparing ShakeMaps.

Goal: To capture on-scale moderate- to large-amplitude ground-motion recordings from earthquakes, particularly in locations near the causative fault or near buildings and other structures that may sustain damage.

Key Components: The standard for recording strong earthquake shaking involves operation of dense as well as sparse networks of strong-motion stations. Some stations may not have communications, but most will use dial-up or continuous communications. Stations are located in urban areas or near critical facilities and lifelines as well as along active fault and in active seismic zones. Urgently needed data include those recorded within 20 km of the earthquake rupture or adjacent to engineered structures that sustained damage due to shaking or that were strongly shaken but did not sustain damage.

Strong motion data are essential for applications such as ShakeMap, and the value of the information can be enhanced through higher station density. Table 3 in USGS Circular 1188 provides recommendations on the regional distribution of stations.

Justification

1. Sensor spacing is primarily designed to provide sufficient resolution for the purposes of generating accurate ShakeMaps in areas with moderate to high risk. For the purposes of emergency response, there may be a greater tolerance for lower resolution maps in non-urban areas with high hazard. See comments above.
2. The network average station uptime reflects the operational goal of maximizing the recording of all earthquakes, while maintaining flexibility if the operation and maintenance of any single station. See comments above.

Real-time Automated Product Generation (Metrics 2.1 – 2.5) and Preparation of Seismologists-Reviewed Products for Significant Earthquakes (Metrics 3.1 – 3.5)

When a significant earthquake occurs, there is need for immediate information to facilitate emergency response and to provide information to decision makers, the media and the public. Federal, state, and local governments are responsible for responding to a significant earthquake. To facilitate efficient response, the seismic networks must provide rapid, consistent, high quality information about the earthquake.

Goal: Automatically and rapidly broadcast accurate information to emergency responders, the media, and the public when a significant earthquake occurs.

Key Components: Seismic networks process earthquake data continuously (24/7) to automatically generate and distribute a variety of products. In general, the products are less accurate just after the earthquake, but their accuracy improves as more data are included and models are refined. Human review, reprocessing, and updating of information follow the automated distribution of information. The products are distributed via short messages (pager and cell phone), email, and the Web.

The performance standards for rapid notification involve timeliness and consistency of initial product delivery. The time delays that contribute to late delivery of products are, for instance, the time it takes seismic waves to traverse the whole seismic network, packetizing delays for waveform data, processing delays, and product delivery delays. Seismic networks may have unforeseen outages and product delivery will not be possible during that time.

In the future, ANSS will consider adding fault modeling specifications for M>6.5 continental U.S. earthquakes and M>7.0 global earthquakes.

Justification:

1. In order to meet the needs of the emergency response community and others, automated products should be produced as quickly as possible while maintaining a reasonable level of product quality.
2. The increased accuracy normally contained in reviewed products reduces uncertainty in decisions based on the information, and increases the value and accuracy of derived products (e.g., hazard assessments) and research results (e.g., tectonic studies).

Data Exchange between ANSS Networks – Metrics 4.1, 4.2, 4.3.

The operational efficiency of seismic networks can be greatly improved through real-time data exchange. Data recorded at stations operated by a neighboring network can provide important information about significant earthquakes, particularly for shocks occurring near the border region of the two networks or where the spatial extents of network operations overlap.

Goal: Share real-time waveforms, amplitudes, picks and other raw data products among regional and national networks to improve quality and timeliness of data products.

Key Components: Unprocessed waveforms are the most basic seismic data that can be continuously exchanged and provide the ability for networks to compute all seismological products. However, the bandwidth required for rapid exchange of waveform data can be considerable, so it may be necessary to exchange derived products such as amplitudes (acceleration, velocity, displacement, spectral ordinates, etc.) for calculation of magnitude and ShakeMaps, arrival times and polarity of seismic waves for computing locations, origin times, and first-motion mechanisms, or "snippets" of waveforms when earthquakes occur for computing moment tensors and analyst review.

Justification

1. Exchange standards for timeliness represent for the most rigorous standards consistent with automated product generation, likely packet size, and anticipated communications bandwidth and availability.
2. Standards are based on existing experience with data exchange throughout the U.S.
3. The current ANSS Backbone packet size is about 50 s of data, sufficient to meet the 60 s standard. A higher sampling rate and wider VSAT bandwidth may be required to meet the 30 second timeliness standard for waveform distribution in high-risk urban areas and moderate – high hazard areas.

Data Archiving and Public Distribution – Metrics 5.1, 5.2, 5.3.

Seismic networks generate data continuously as they monitor seismicity. When an event is detected, the respective window of waveforms is typically stored for later archiving. Similarly, at the onset of detection, products such as phase arrival times, amplitudes, hypocenters, magnitudes, mechanisms, ShakeMaps, and slip distributions may be generated. In some cases, seismic networks record continuous data from broadband data.

Goal: Following ANSS Data and Data Products Policy, all relevant data and data products generated by ANSS, including the regional and global seismic network, shall be made readily available and archived at public datacenters.

Key Components: The datacenter(s) must balance the archiving of data from the seismic networks against the speed at which they serve data to the users. Data archiving occurs on a regular basis, whereas user requests for data may be episodic. Consequently, during a major earthquake sequence a data archive will need to be able to deal with increased data volume (input) as well as an exponential increase in user requests (output). Some data archives presently provide data to users via command-line scripts, while most use Web pages, web services, and ftp as transfer mechanisms. In the future all data archives should provide data via the mechanisms just cited, as well as via simple subroutine calls. Similarly, data formats are evolving from legacy binary or ASCII formats to XML. One of the challenges facing datacenters is to import decades of legacy date into modern database structures to be able to serve up the data in a variety of ways as dictated by user needs.

The data archiving performance standards address several aspects of the datacenter operations. First, the datacenter needs to import data in a timely fashion. Products such as waveforms and parametric data should automatically be made available to users with minimal delay. The datacenters need to be able to serve a large number of users during periods of high demand. Metadata must be provided to describe station characteristics and instrument responses; thus the "metadata availability" ensures the availability of station instrumentation responses needed for all products based on amplitude information.

Justification

1. Standards for data import into the archive provide a reasonable balance between the desires of key users and the abilities of the system.
2. Availability of the data should provide sufficient time for archive construction and processing.
3. "Dataless SEED" and "V0" are standard formats that contain necessary sensor calibration for seismic waveform data exchanged between networks.

A Note on Education and Outreach

The end users of products from ANSS seismic network include large communities of emergency responders, earthquake engineers, decision makers, education community, media, and public. While the ANSS initiative does not include a focus on 'Education and Outreach" *per se*, in order to provide reliable, useful, accurate, and timely release of products to these and other target communities, education will need to be provided either directly or through partnerships with organizations that do E&O. The principal goals of this education are to minimize product misuse, to maximize the use of monitoring products, and to generate feedback for long-term product improvement. Specific minimum standards on dissemination goals and product/data use are difficult, if not impossible, to quantify. Determination and implementation of appropriate metrics will require expertise external to existing ANSS operations and management.

History of this document

This document is based heavily on the draft report of Working Group A (Performance Standards) of the ANSS Technical Implementation Committee, chaired by Mitch Withers of the Center for Earthquake Information of the University of Memphis, which compiled its report in 2004-2005. That report is available on the ANSS/internal web site *(http://www.anss.Org/internal/a)*.

This document is reviewed and revised as needed by the ANSS Coordinator, ANSS Integrated Products Team, and the ANSS National Implementation Committee.

Initial Release Version 2.6	date: 16 January 2007
Revision 1, Version 2.7	date: 5 October 2008
Revision 2, Version 2.8	date: 13 May 2014 (approved by the NIC)
Revision 3, Version 2.9	date: 17 May 2019 (approved by the NIC)